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Science Advisory Report 2012/018

BIOMASS LIMIT REFERENCE POINT CONSISTENT WITH THE PRECAUTIONARY APPROACH FOR AMERICAN PLAICE (*HIPPOGLOSSOIDES PLATESSOIDES*) FROM THE SOUTHERN GULF OF ST. LAWRENCE (NAFO DIV. 4T)

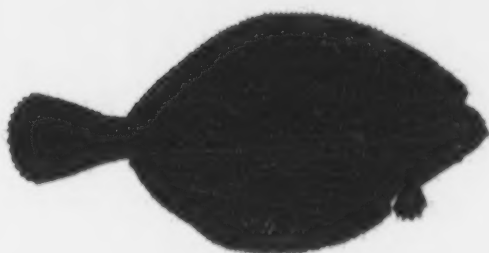


Image : Goode & Bean, 1896



Figure 1. Map of the southern Gulf of St. Lawrence showing NAFO Division 4T.

Context :

Canada, as signatory to the United Nations Agreement on Straddling and Highly Migratory Fish Stocks (UNFA) has committed to using the Precautionary Approach (PA) in managing stocks. In 2009, DFO completed a policy document entitled "A fishery decision-making framework incorporating the Precautionary Approach" which explains in detail how the precautionary approach will be put into practice. To be compliant with the Precautionary Approach, fishery management plans should include harvest strategies that incorporate a Limit Reference Point that delimits the critical/cautious zones, an Upper Stock Reference that delimits the cautious/healthy zones on the stock status axis, and a Removal Reference that defines the maximum removal rate in the healthy zone. DFO Fisheries and Aquaculture Management (DFO FAM) requested advice from science to define the reference points compliant with the Precautionary Approach framework for the American plaice stock from the southern Gulf of St. Lawrence, NAFO Div. 4T. Guided by the DFO policy on the PA for fisheries, a regional advisory process meeting was held Feb. 21, 2012 to review proposals and to define reference points for this species and stock. The review was provided by participants from DFO Science, DFO FAM and from the fishing industry.

SUMMARY

- An age-structured population model to estimate spawning stock biomass and recruitment was updated to 2011. Model estimates of the spawning stock biomass (SSB) show a general decline from the late 1970s to the early 2000s. SSB was at its lowest level in 2009 at less than 31,000 tonnes; the latest estimate (2012) was 41,676 tonnes.

- Age-4 recruits were most abundant in the late 1970s, up to 13 times their average abundance over the last five years. Recruitment has fluctuated at a low level since the early 1980s.
- The dynamics of the 4T plaice stock are dominated by a pattern of high natural mortality on adults, combined with chronic poor recruitment.
- Model estimates of SSB and their corresponding recruits at age-4 formed the basis for analyses of the stock-recruit relationship.
- Based on Beverton-Holt and Ricker stock and recruitment models, the median SSB that produced 50% of maximum recruitment ($B_{50\%}$) is estimated at 68,000 and 60,000 tonnes, respectively.
- The $B_{50\%}$ value for 4T American plaice is defined as the average of the estimates from the Beverton-Holt and Ricker models, 64,000 tonnes. The SSB for the 4T plaice stock has been met or exceeded $B_{50\%}$ once since 1996.
- Fishing mortality (F) was negligible on 4 to 9-year-old plaice throughout the time series, but for older plaice, estimated F varied between about 0.1 and 0.2 from the mid 1970s to the early 1990s, falling to below 0.01 in recent years.
- Data and analyses were insufficient neither to define the removal rate limit reference point (F_{lim}) nor to propose candidates for the upper stock reference point (B_{USR}).

BACKGROUND

Reported catches of American plaice in NAFO Division 4T ranged between 6,000 and 12,000 tonnes from 1965 to the late 1980s. Preliminary landing statistics for the 2011 fishery are at approximately 90 t, the lowest level on record. The Total Allowable Catch (TAC) was 10,000 tonnes from 1977 – 1992, with a high level of discarding in the mobile gear fishery. In 1993 the TAC was dropped to 5,000 tonnes and several management measures were introduced to prevent discarding. Subsequent reductions were made to the TAC and since 2008, it has been maintained at 500 tonnes. Recent landing declines have been attributed to decreasing effort brought on by a combination of high cost associated with exploitation (mainly fuel), poor market conditions, weak demand for the product, low quota, and low catch of large, higher quality plaice.

In April 2009, the Committee on the Status of Endangered Wildlife in Canada assessed the Maritime Designatable Unit (DU) of American plaice, which includes the southern Gulf of St. Lawrence stock, as "threatened" (COSEWIC 2009). A Recovery Potential Assessment (RPA) conducted in March 2011 established that the 4T plaice stock was at a low level of abundance and showed no signs of recovery, despite recent low harvests (DFO 2011). Major contributing factors to the lack of recovery were persistent low recruitment and a high level of natural mortality acting on all ages (DFO 2011).

Biology

American plaice are widely distributed throughout the Northwest Atlantic, from west Greenland to the Gulf of Maine, at intermediate depths usually ranging from about 80 to 250 m. They prefer cold water temperatures in summer of 0 to 1.5°C. In the southern Gulf of St. Lawrence they prefer depths of about 60 m in summer, but move to deeper channel waters to overwinter at depths over 370 m. Their growth is slow in the southern Gulf, females reaching an average size of 30 cm (the commercial limit) by about 8 years of age. It may take males 11 years or more to

reach 30 cm. The size and weight-at-age of plaice, as measured in research surveys, have declined over the past 40 years. Plaice may live to 30 years of age in the southern Gulf (last observed in commercial sampling of the late 1980s). The maximum size and age of plaice have declined over time, such that the oldest plaice in the 2010 and 2011 fisheries were 22 years of age.

ANALYSIS

An age-structured population model for 4T American plaice was used to develop a comprehensive view of stock dynamics, including trends in the abundance of recruits and the parent stock, and estimates of mortality. Since 2010, the commercial catch-at-age has included estimates of discarded plaice, extending back to 1976.

The longest index of 4T American plaice population abundance and of the size and age structure originates from the annual depth stratified bottom trawl ecosystem survey, conducted every September since 1971. The abundance indices from this survey are expressed as the stratified mean catch per tow, adjusted to a common survey vessel and trawl. Total mortality (Z) was estimated from the survey catch-at-age by a catch curve analysis that estimates Z as the slope of log-transformed catch in short time periods, accounting for variation in year-class abundance.

The mobile gear sentinel program was also used as an index of 4T American plaice abundance in the population model. Since 2003, this program has used a 300 Star Balloon otter trawl and adopted the same stratified random sampling design that is used in the annual September ecosystem survey. Seven trawlers have participated in the mobile gear sentinel program since 2003 and four vessels conduct the survey each year, overlapping in their coverage to allow a comparison of their relative fishing efficiency.

The population model was based on a Virtual Population Analysis (VPA) implemented in AD Model Builder. Model inputs were the commercial catch-at-ages 4-20+ years in 1976 – 2011, revised to include estimates of discarded plaice, the RV abundance indices at ages 4 – 18 years in 1976 – 2002 and 2004 – 2011, and abundance indices for ages 4-18 years from the 2003 to 2011 sentinel bottom-trawl survey. The variation in natural mortality (M) was modelled as random walks, with separate trends for ages 4-9 and 10+ years.

Status

The ecosystem survey index shows that the stock was at a low level of abundance in 1971, but increased rapidly through the mid-1970's to attain a maximum of 917 plaice per tow in 1977 (Fig. 2). The stock declined in abundance after 1977 and, by 1984, abundance was well below the long-term average of 266 plaice per tow. The survey index reached its lowest point during the 2002 survey at 104 plaice per tow. The survey index remains at a low level, but it has fluctuated in the last four years. In 2010, the index increased to 192 plaice per tow due to two exceptional catches in the northwestern part of 4T (catches of 5,900 and 4,008 plaice per standard tow, respectively). Catches of more than 4,007 plaice per standard tow have only occurred nine times in previous surveys, the last time in 1991 and seven times between 1976 and 1980. When the two large catches in the 2010 survey were removed, the abundance index dropped to 130 plaice per tow. The abundance index in 2011 was 152 plaice per tow.

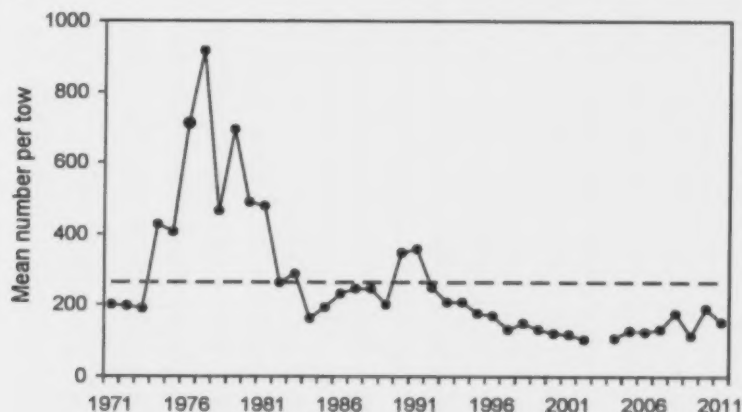


Figure 2: Trawl survey index for 4T American plaice. The dashed line indicates the mean annual catch (266 plaice per tow).

The sentinel survey catch index, adjusted for vessel effects, shows a declining trend since 2004 with an increase occurring in 2011.

Total mortality (Z), estimated from the survey catch-at-age, has varied from less than 0.3 in the early 1970s to 0.58 in 1978-1982, to a low of 0.24 in 1982-1986, followed by a high of 0.83 in 1991-1995 (Fig. 3). The trend in Z appears to have leveled off since the late 1990s near the average of 0.52, despite recent harvest reductions. Z was estimated at 0.46 in the last two 5-year periods.

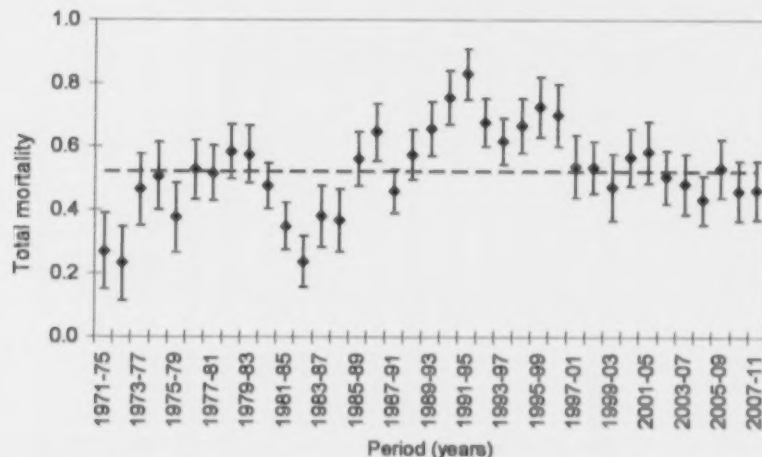


Figure 3: Total mortality of 4T plaice between 7 and 20 years of age, based on multiplicative models of survey catch data in 5-year periods with 95% confidence limits as vertical bars. The horizontal broken line is the mean of all estimates since 1971 (0.52).

Previous assessments of 4T plaice have shown that the survey length frequencies have shifted over time to smaller sizes, with a more rapid decline in the upper quantiles of fish length (Morin et al. 2008). This pattern suggests a loss of larger plaice from the population, a result that is consistent with the high estimates of total mortality for age 7-20 plaice.

The spawning stock biomass (SSB), estimated from the population model, generally declined from the late 1970s to the early 2000s (Fig. 4). Current SSB, estimated for January 2012, is 41,676 t. Recruit abundance (at age 4) in the mid to late 1970s was estimated to be up to thirteen times the average value over the last five years (Fig. 4).

Estimated M of pre-commercial sizes of plaice (ages 4-9 years) was highest in the late 1970s, declining to a level between 0.5 and 0.69 throughout the 1990s and 2000s (Fig. 5). The high level estimated for the late 1970s may partly reflect an underestimate of the level of discarding during this period. For older plaice, estimated M was between 0.19 and 0.28 in the late 1970s and early 1980s, increasing to a peak of 0.64 in the early to mid 1990s and then decreasing to 0.4 – 0.45 throughout the 2000s (Fig. 5). Estimated fishing mortality F on pre-commercial sizes (ages 4-9) was negligible throughout the time series, at a level near 0.01 from the mid 1970s to the early 1990s, declining to a level <0.001 in the 2000s. For older plaice, estimated F varied between about 0.1 and 0.2 from the mid 1970s to the early 1990s and then declined, falling to a level below 0.01 in recent years.

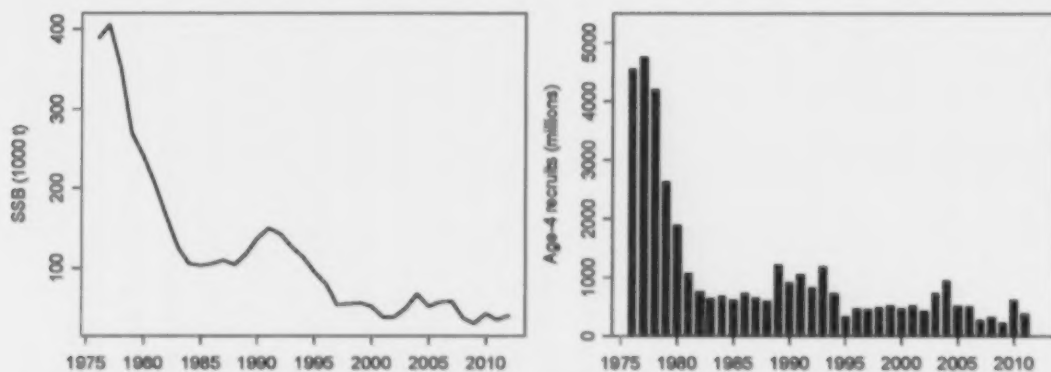


Figure 4: Estimated spawning stock biomass (SSB; left panel) and abundance of age-4 recruits (right panel) for the 4T plaice population.

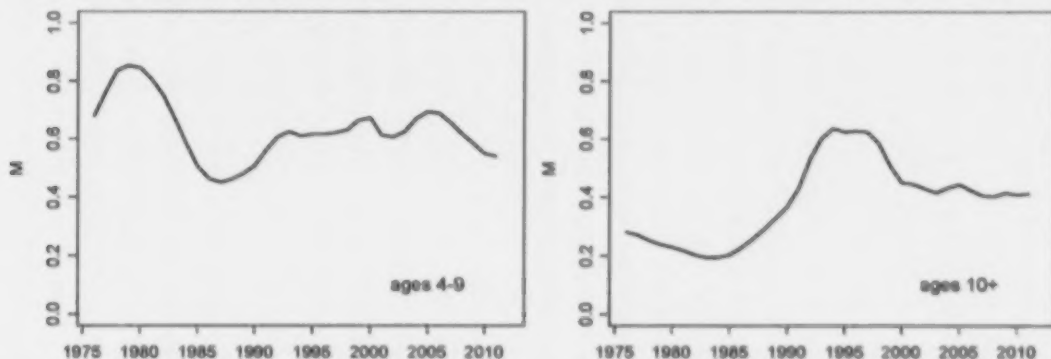


Figure 5: Estimated instantaneous rate of natural mortality M for age groups 4-9 (left panel) and 10+ years (right panel) in the 4T American plaice population.

Defining reference points for southern Gulf American plaice

Reference points have never been defined for the 4T American plaice stock.

DFO (2009) provides guidance on the derivation of both the stock status (biomass) and removal rate reference points for the PA framework. For stocks with age-structured analytical assessments, such as 4T American plaice, the spawning stock biomass is used as a measure of stock productivity. The stock would be in the critical zone if the stock status indicator is less than or equal to 40% of biomass that produces maximum sustainable yield (B_{MSY}). The stock would be in the healthy zone if the stock status indicator is above 80% of B_{MSY} . B_{MSY} may be defined from the slope of the stock-recruit relationship, as it defines stock surplus in relation to a hypothetical replacement line. When the level of recruits required to replace SSB is poorly defined, an alternative to 40% of B_{MSY} may be the SSB associated with 50% of maximum recruitment ($B_{50R_{MAX}}$, DFO 2004). Another proxy limit reference point considered is called $B_{RECOVERY}$, the lowest historical biomass level from which the stock recovered readily or produced good recruitment (DFO 2002, 2004).

Stock-recruit relationship

The model estimates of SSB and the number of age-4 plaice recruits produced by that SSB are shown in Figure 4. The last estimate of SSB for which there is a corresponding estimate of recruits four years later is 2007. SSB in 2007 was estimated as slightly less than 59,000 tonnes. However, SSB has continued to decline, reaching its lowest point in 2009, at less than 31,000 tonnes (Fig. 4). The latest estimate, for 2012, was 41,676 tonnes.

Recruitment was at its recorded peak early in the time series, in the 1970s and the highest level of recruitment for which there is SSB values occurred in 1976 with SSB at approximately 388,000 tonnes. That level of SSB was exceeded in the following year (405,000 tonnes), but failed to produce the same level of recruitment (Fig. 6). Recruitment rate, expressed as the number of recruits divided by the number of spawners that produced them (SSN), has cycled through high and low periods. The 1985-1989 and 2000-2002 cohorts appear to have been abundant relative to the spawning stocks that produced them.

Options for Limit Reference Points (LRP) were initially evaluated using eight stock-recruitment models (Duplisea and Fréchet 2009). The LRP from three parametric models (Beverton-Holt, Ricker, and Hockey Stick) and from one non-parametric model (spline fit) was defined as the SSB that produces 50% of maximum recruitment. $B_{50\%}$ is an empirical definition of the LRP based on the lowest observed SSB from which a recovery to 30% of the maximum observed SSB occurred.

The Beverton-Holt and Ricker models were retained for estimating the LRP. Based on non-linear regressions, the LRP estimate from the Beverton-Holt model (BH50) was 81,000 t and from the Ricker model (RK50) 77,000 t. The Hockey Stick model produced the lowest estimate of the LRP (43,000 tonnes) of all eight models that were applied to the data. The spline model was not credible in defining a plateau corresponding to maximum recruitment and two other non-parametric models based on spline fits were also rejected. $B_{RECOVERY}$ identified a recovery from 104,000 tonnes in 1985 to 30% of maximum SSB. This recovery was not sustained, probably due to rising natural mortality on adult plaice that peaked in the early 1990s (Fig. 4). A Serebryakov model based on 90% recruitment and 90% SSB survival (S90/90) estimated the LRP at 106,000 tonnes.

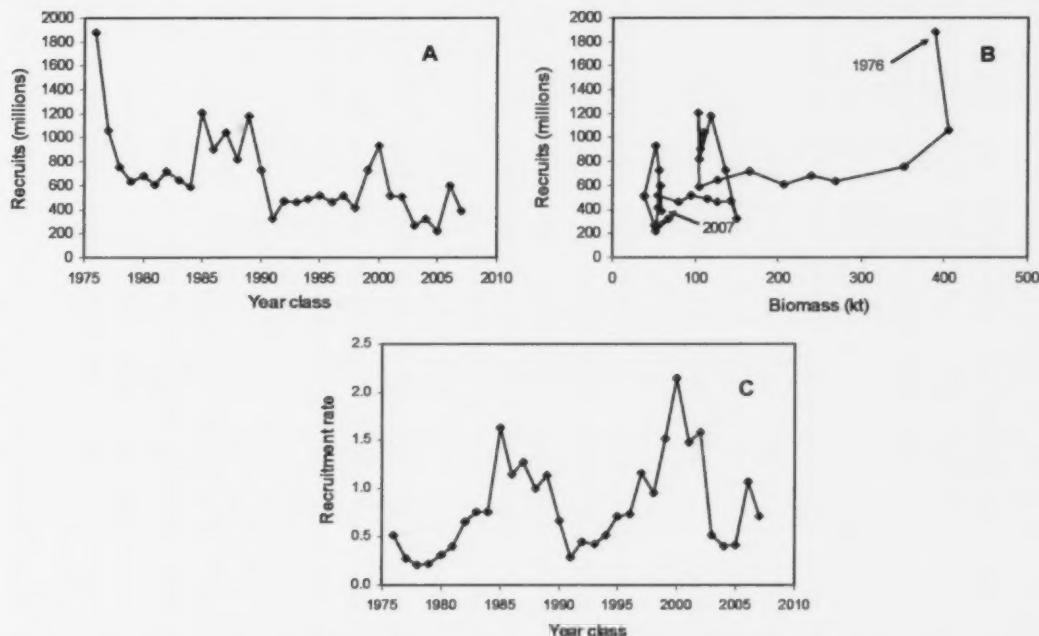


Figure 6: Stock-recruit relationships based on population model estimates. A: the abundance of age-4 recruits by year-class. B: the relationship between spawning stock biomass (SSB) and the number of 4-year-old recruits. C: the ratio of the abundance of age-4 plaice to the number of spawners that produced them (recruitment rate).

Applied to 4T American plaice data, the Beverton-Holt and Ricker models produced intermediate estimates of the LRP amongst the more credible models considered. We examined further the properties of BH50 and RK50 in a Bayesian framework. Both models were fitted to the 4T American plaice median population model estimates of SSB and age-4 recruits. The Bayesian median estimate of BH50 was 68,000 t (95% BCI 13,000 to 221,000 t) and 60,000 t for RK50 (95% BCI 42,000 to 105,000). As with the non-linear regression models for Beverton-Holt and Ricker, the two models provided similar fits to the stock-recruit data. The credible range for RK50 is more restricted than that of BH50; however, there is limited evidence for a decline in recruitment over the upper range of SSB (Fig. 7). The recommended LRP for this stock is the average of the estimates of BH50 and RK50 at 64,000 tonnes.

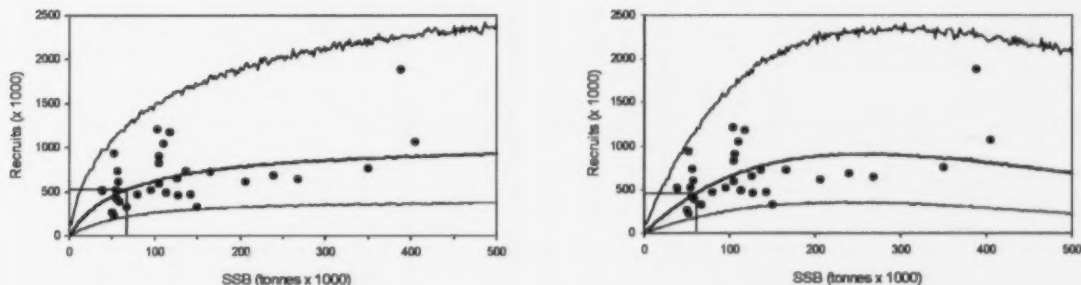


Figure 7: Beverton-Holt (left panel) and Ricker (right panel) spawning stock biomass (SSB) and recruitment fits (median and 95% BCI lines) for 4T American plaice. Data points are estimates of SSB and age-4 recruits for the 1976 to 2007 cohorts. Vertical and horizontal lines correspond to recruitment and SSB at half of model estimate of maximum recruitment.

The history of stock performance relative to this reference point is shown in Figure 8. The 4T plaice stock has failed to reach the LRP in 15 of the past 16 years, last attaining it in 2004 at over 67,000 tonnes. It is to be noted that this low stock performance was observed during a period of low fishing mortality.

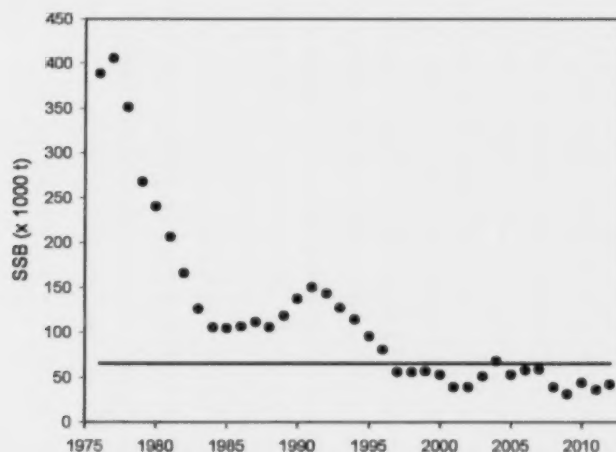


Figure 8: Estimated spawning stock biomass (SSB), 1976-2012 (points) and recommended lower reference point of 64,000 tonnes (horizontal line).

Uncertainties and knowledge gaps

There are uncertainties in the identification of maturity stages for 4T American plaice prior to 1997. As a result, annual maturity ogives were used since 1997, whereas a constant maturity ogive was applied to the 1976-1996 period. This may affect the estimation of the SSB that resulted from the population analysis. There is evidence from other 4T groundfish species that maturation changed over the 1976-1996 period and a decline in the size and age at maturity was found for 3LNO plaice. However, the 4T plaice population model accounts for other changes that have occurred, such as changes in the size and age composition of the SSB, as well as mortality effects on the SSB. The residual pattern of the stock-recruit relationship indicates that the time series has been stationary.

As with most Atlantic groundfish stocks, 4T American plaice were exploited for many decades before our data series began. The 4T plaice commercial catch-at-age began in 1976. The first observed cohorts were the most abundant; however, survey data indicate that cohorts originating from spawning before 1976 were considerably stronger. The lack of data from this period may affect the definition of the Healthy zone for this stock. It may also imply that the defined stock-recruitment relationship does not adequately describe the dynamics of the 4T plaice stock in a more productive period prior to 1976.

CONCLUSION

Several indicators of the status of 4T American plaice suggest that the stock is presently at an all-time low abundance level. A survey conducted annually for the past 41 years indicates low abundance. Commercial fishing has been reduced to less than 500 tonnes annually for most of the 2000s, with 90 tonnes landed in 2011. Despite low harvests, the stock shows no signs of

rebuilding. Total mortality estimated from recent survey data is at 0.46 for plaice aged 7-20 years. There has been a reduction in the maximum size and age of 4T plaice consistent with high mortality on older fish.

A population model of 4T American plaice indicates that the spawning stock biomass has declined since the late 1970s to its lowest level in 2009 (31,000 tonnes). In 2012, the SSB was estimated at about 42,000 tonnes. Recruitment has been chronically low: 13 times less over the past five years than at its maximum in the late 1970s. Natural mortality on plaice aged 10+ increased in the 1980s to a peak of 0.6 in the early 1990s and has been between 0.4 and 0.45 in the 2000s.

The recommended biomass Limit Reference Point (B_{lim}) for American plaice in the southern Gulf of St. Lawrence, defined as the SSB that produces 50% of maximum recruitment based on Beverton-Holt and Ricker models, is 64,000 tonnes. The SSB has equaled or exceeded B_{lim} only once since 1996. The lack of any consistent improvement in this stock relative to B_{lim} over the past 16 years calls attention to the potentially difficult task of rebuilding this stock. It will be important to continue to monitor recruitment and the survival of cohorts. Further work is required to define the removal limit reference point (F_{lim}) and for the development of the upper stock reference point (B_{USR}).

SOURCES OF INFORMATION

This Science Advisory Report is from the February 21, 2012 meeting on the Reference points for American plaice (*Hippoglossoides platessoides*) from NAFO Division 4T. Additional publications from this process will be posted as they become available on the Fisheries and Oceans Canada Science Advisory Schedule at www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

- COSEWIC. 2009. COSEWIC assessment and status report on the American Plaice *Hippoglossoides platessoides*, Maritime population, Newfoundland and Labrador population and Arctic population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. x + 74 p.
- Duplisea, D. and Fr chet, A. 2009. Precautionary reference point estimates for northern Gulf of St. Lawrence (3Pn4RS) cod (*Gadus morhua*) and methods for their calculation. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/097. iv + 24 p.
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